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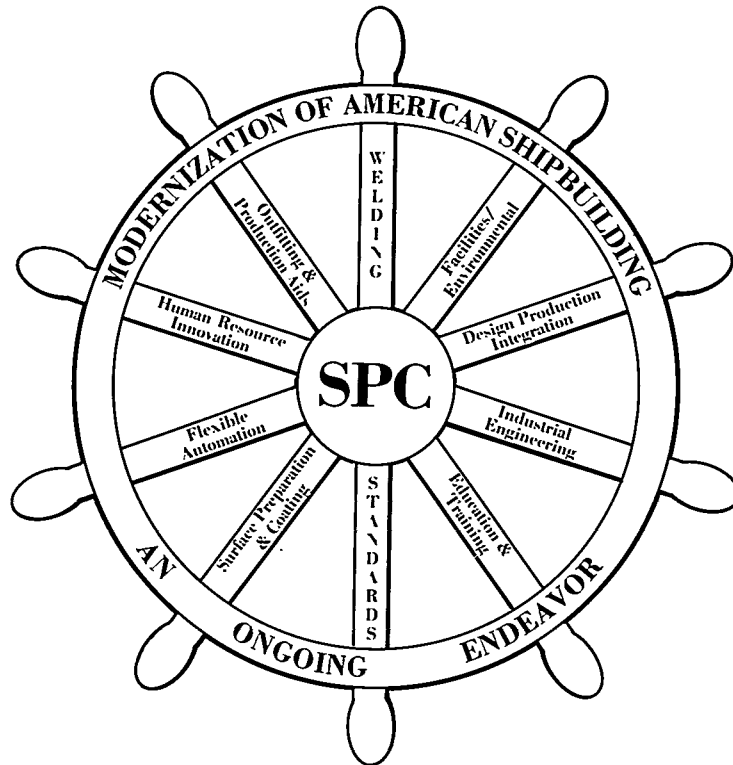
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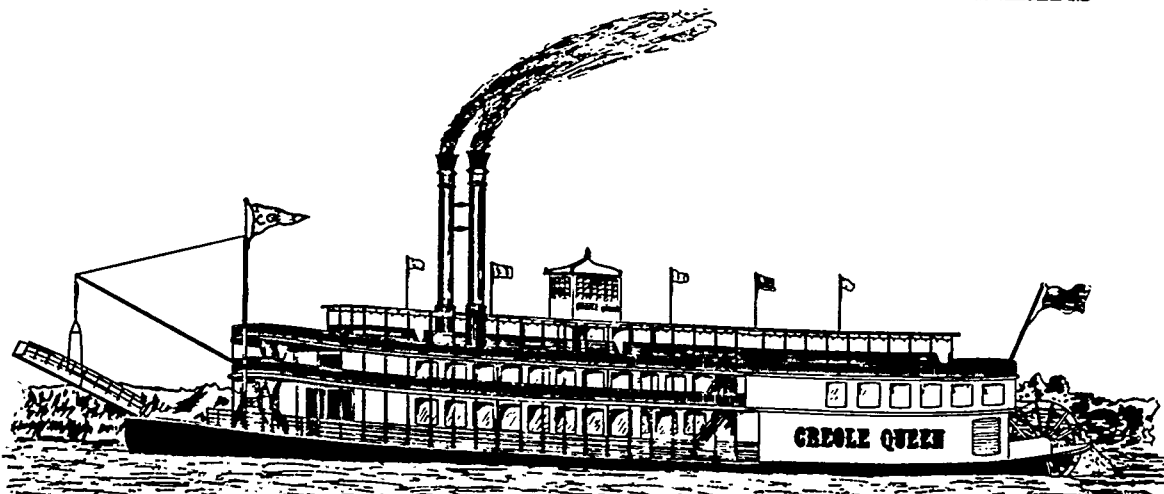
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Ship Design for Production—Some UK Experience No. 18

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ABSTRACT

Ship Design for Production is widely accepted in principle. Its successful establishment depends on the shipbuilder having a well-defined shipbuilding policy, available to the designer, the establishment of a realistic and agreed schedule and adequately trained personnel. Key production engineering techniques include spatial analysis, process analysis and standardization.

The advent of powerful and inexpensive computer software has created new opportunities for producibility to be incorporated from the earliest stages of the design process. Significant progress has been made in recent years in the development of design methods, and in their application.

1: DESIGN FOR PRODUCTION

1.1 Introduction

Ship Design/Production Integration - Design for Production - is an idea that few would disagree with but that almost all would wish to qualify. Dependent on the individual viewpoint, design for production lies somewhere on a scale between building ships with no curves in the hull form and allowing minor modifications to bracket. In reality, it is like most design activity, compromise. A working definition would be:

Design to reduce production costs to a minimum, compatible with the requirements of the vessel to fulfill its operational functions with acceptable reliability and efficiency. (Ref 1)

The role of the ship designer can be seen in this context as one of arbiter, having the ultimate responsibility of deciding whether performance or production considerations shall take precedence in any particular case or of deciding the nature of the compromise to be reached.

The extension of the design process to include a design for production function has the following primary objectives:

To produce a design which represents acceptable compromise between the demands of performance and production and where appropriate takes into account the needs of overhaul, repair and maintenance.

To ensure that all design features are compatible with known characteristics of shipyard facilities.

To coordinate the inter-relationship between the machinery, electrical and outfitting work with the structural work, in order to create a fully integrated design.

It is vital that design for production effort start early in the design process. Designers have the greatest influence on the cost of the vessel during the earliest design stages when main materials and equipment and the basic configuration are being decided.

1.2 The Need for Integration

The need for Design/Production integration arises from changes in the production system itself. Traditionally, construction cycle times were long and the achievement of high throughput were made possible by multiple-ship, simultaneous construction. Steelwork preceded outfit work and outfit work was carried out almost entirely after the erection and launch of the steel hull. Nowadays, production cycle times have become shorter as pressure from the market has dictated lower prices and faster delivery times. Steelwork and outfitting are now carried out in parallel. The change in production system has led to the need for the technical system to provide information in a different timescale, sequence and format.

The need? for people in the technical functions to understand production requirements and for production departments to understand technical procedures and requirements is greater than ever. It is not possible to achieve low production times, short delivery times and high productivity unless technical and production functions work closely together.

1.3 Shipbuilding Policy

Design for production effort can achieve its greatest impact only if the company has developed a shipbuilding policy. The objective in defining a company shipbuilding policy is to establish a "standard" approach to ship construction. This can be achieved through the following step-by-step approach:

1. Develop a product work breakdown structure (Ref 2). The basic aim is to subdivide the ship into a narrow range of interim product types. Each product type may be identified by the sequence and nature of the operations involved in its manufacture and assembly.
2. Establish the "ideal" ship construction method and sequence, to optimize material sizes, subdivide hull into planning units and develop an "ideal" production sequence.
3. Identify shortfalls in the capacity and capability of existing facilities to meet the requirements of the ideal construction method.
4. Determine the best compromise solution and draw up proposals for the removal of the constraints identified above, as the basis for a master plan for future facilities development.
5. Develop standard manufacturing methods and a standard list of operations for each product type. These standard methods must be documented and provided to the designer in order for the design function to be supportive to them.
6. For each ship type and size to be constructed, determine the workload for each product for planning resource requirements.
7. Identify workstations for the manufacture and assembly of each interim product type and determine relevant manning levels.

Shipbuilding policy, of course, must be dynamic and responsive to changes in technology, methods and facilities.

1.4 Design for Function

The prime objective of the ship designer must be to create a vessel which will perform certain functions. It must operate as specified by the shipowner, for example:

- travel at a given speed,
- operate at a given fuel consumption,
- carry a given payload,
- meet classification and other regulations.

Within the lifetime of the vessel, it is inevitable that some of the sub-systems will require to be replaced and their replacement may even be planned from the initial phase. Further, many of the systems will require routine maintenance during their lifetime and there is also the possibility of damage during the vessel's lifetime. In designing for function, all of these additional considerations must be taken into account. In the context of Design for Production, the question must be asked as to what impact a production-oriented approach will have on the various functional requirements specified.

The structured approach to design outlined in this paper based on the development of a vessel as a hierarchy of functional spaces, allows a variety of potentially conflicting requirements to be met. The design which enhances producibility can also enhance operating characteristics.

1.5 Build Strategy (Ref 3)

The planning of large single projects is usually very complex, due principally to the lack of related experience data. It follows that if large sections of any project can be identified as very similar to work done on earlier projects then these may be planned and scheduled with a higher degree of reliability. Those shipyards which have developed a consistent approach to the building of ships have extended this concept to basic design. The fundamental objective with this approach is to develop an established "game plan".

Each new or potential ship contract received by the shipyard requires the

formulation of a build strategy. The build strategy applies the shipbuilding policy to a particular contract. Where a shipyard has been working to a relatively uniform construction method over a period of years, much of the work on the build strategy would be produced quickly with most attention being given to those areas identified as being novel.

Products change over a period of years and as production facilities and methods are developed, a considerable drift can occur. Ship designs may not be updated to match new facilities and the production methods may not be optimised for new design requirements. A formal method is therefore needed which will enable changing requirements to be identified and absorbed systematically.

Thus, it is essential that each new ship undergo a systematic scrutiny to determine the proposed construction method, to list key events and their timing with respect to the overall project duration, and to identify possible problem areas and bottlenecks so that these can be resolved before production begins. The output from the evaluation of the vessel and the definition of the means of producing it is the contract build strategy. Part of the strategy may include the modification of facilities, or changes in work practices.

1.6 Role of Planning

Following the definition of what production work is to be carried out, and how it is to be done, the planning function has the main task of determining when work is to be carried out. Planning must relate not only to the activities of the production departments, but also to the provision of information from design, and other technical areas. In this respect, the planning function acts as an important communication link between design and production.

Planning follows production engineering. For example, in the outfitting of a ship, the sequence would be to establish the planning units (zones and steelwork), develop the production sequence and then establish a sequence of work packages for each planning unit. (Figure 1)

The planning department will then work backwards from these dates to establish other key dates in the program. For example:

- Latest date for fabrication of outfit assemblies.

- Latest date for delivery of materials.
- Date for ordering materials.
- Date when technical information from suppliers is required.
- Start date for drawings.

A more detailed level of planning is called for in which the planning office no longer demands the whole of a particular system to be completed by design by a particular date but, instead, demands that all systems within a particular zone are completed and by which date it must be done.

1.7 Training

For design/production integration to be carried out effectively requires properly educated, trained and shop-floor-experienced people. In Japan and Scandinavia in particular, shipbuilders have had a clear policy for many years for the training and development of shipbuilding engineers. Elsewhere too many designers are in the position of having to make major design decisions having barely seen, let alone worked in a shipyard. Another major feature of the successful implementation of design for production is discipline. The preproduction effort will be largely wasted unless production has the discipline to follow the determined program, methods and procedures, and this requires training.

It is not possible merely to prepare "standards" and document them in such a way that a designer with no production knowledge can prepare a design with inherent producibility. Both the vessel technology and the methods of production are dynamic. There are also areas where interpretation of the production or design standard is needed. For this interpretation to reflect the requirements of design/production integration, it is essential that the designer has an understanding of the production process.

One method of resolving the problem is to ensure that all new design staff spend a period before, during or immediately after their formal design training working in a shipyard production area. Even assuming that during the period of initial training, design personnel are well trained with experience of production methods, as these change there will be a need to update the designer's previous experience.

1.8 Formal Communication

The volume of necessary communication between the design and production functions is such that a formal set of procedures is essential. The basis of such communication is the input and output associated with the main stages of design. Responsibility for the preparation of each element of the total set of information will be defined by terms of reference. Even in cases where the design and production functions are part of the same company, it is not uncommon for the communication between them to be poor. It is possible to find designers who have not seen the production facilities of the shipyard in which they operate.

Determining the information requirements is a function of production engineering. Production engineering will act as a link between the design function, the production function and planning. The formal communication will include a definition of the information to be supplied, the timing of that information and the various sets of standards and regulations which will apply. Not only the form of communication (drawing, sketch, schedule, computer tape) but also the content should be specified, by example.

1.9 Coding

Coding systems are required for item identification, planning and work ordering, cost control and drawing identification. The term "item identification", rather than "part numbering", has been deliberately used since identification in the fullest sense is the primary function of the numbering system. When developing hull steel and outfit numbering systems, it is essential that 'identification' includes at what stage it is made and into which planning unit it is installed. Items which are produced repetitively may be identified as ship standard or stock items. These items would be appended to the planning unit or interim product by item lists.

Coding systems can be for identification or classification. Identification codes can be very simple, and many material control systems use unique part numbering with no structure at all to the identification code. All like items have the same code and the computer system keeps track of which parts go to make up which assembly by holding details of the product structure. At the other extreme, some code systems try to pack very large amounts of information into code.

Classification codes carry information on things like part type, material type and specification, whether or not the part will be installed on a steel unit or block and the number of the work package of which the item will be part. This information classifies the item but is not needed to identify it. Information of this type can be held as attributes of the part and should not be included in the identification coding.

It is likely that the code system will in fact carry a mix of identification and classification elements in order to make it user friendly. The codes should therefore have some structure without becoming too long or complex. The structure should reflect the hierarchy of interim products and the relationship between workstations and departments or cost centers. The way to design or assess a code system is to consider the information required out of the system and then develop the structure that will allow that information to be obtained quickly and easily. The key point to remember is the difference between identification and classification. There is no need to try and hold too much classification type information in an identification code.

2: APPLICATION OF PRODUCTION ENGINEERING

2.1 Spatial Analysis

Process and spatial analysis are the basis for design/production integration. Spatial analysis develops the complete ship design as a series of related functional spaces or spatial envelopes. At preliminary design the designer develops the design by aggregating standard envelopes to define, for example, the arrangement of a machinery space. The designer need not necessarily know the details of the envelope content to define the arrangement. If the arrangement alters this does not delay the lower levels of design as the details of what is contained within an envelope can be developed independently and in parallel. The size of each envelope is determined from standards or an analysis of outfit assemblies. In the ideal situation the contents of the envelope will themselves be standard. The standards are developed on the basis of previous experience, analyzing vessels to determine how envelopes can be defined for future contracts.

Once the series of spaces have been defined, they are aggregated to build up a picture of the whole vessel. Each spatial envelope includes not only the

equipment, or structure within it, but also operating space requirements, access ways, maintenance and withdrawal spaces. (Figure 2)

Spatial analysis determines the layout of a vessel. It must be integrated with hydrodynamic and other requirements defined by the naval architect, to ensure the ship will operate properly. Benefits of the spatial analysis approach for the designer are the ability to use standards and the ability, after the analysis, to work independently on the detail design of the content of the envelopes. For the producer, the benefits are the incorporation of standards and the ability to relate design timetable to production requirements.

2.2 Block Breakdown

In order for the design of a ship to be suited to efficient production in a particular shipyard, the designer must be aware not only of the shipyard facilities but also of standard or preferred processes and methods used by production. This information must be documented and available to the designer in increasing detail through the design process.

At the earliest design stage the need is for a block breakdown, showing the preferred erection method. This is then extended to information on how each block is assembled. At the detail design level information is required, such as welding processes and accuracy control methods. The breakdown for the ship is reviewed and amended as necessary by the design and production departments, taking into account any unusual design features of the ship or changes in production methods.

2.3 Process Analysis

Process analysis is part of both strategic and tactical production engineering. The basis for process analysis is the planning unit, which is the central entity around which production engineering and planning work is organized. Typically a planning unit is a block, or a pair of blocks, an outfit unit or a zone on-board the ship.

Having identified the planning units, production engineers decide upon the sequence of work to complete the planning unit in the required time and to the required level of quality. Production engineers will define what work has to be done at each production stage, and at which work station work has to be done. To be effective,

production, design and planning people should be involved in the process analysis work. (Figure 3)

At the strategic level some process analysis will be specific to contracts, for example, identifying where and how planning units for a particular ship differ from the standard. Other work will center around the development of the standards themselves. At the tactical level, process analysis will be carried out in detail for all planning units. Technical inputs will come from transition design and the outputs will be used as the basis for the preparation of work station drawings. (Figure 4)

Process analysis therefore provides detailed information that forms the basis for the preparation of work station drawings and for production. At the same time, the analysis may well lead to the identification of improved production methods. These improved methods would be incorporated in the shipbuilding policy and then in future designs.

2.4 Technical Information for Work Packages

In order to plan, control and monitor production work effectively, the work is best broken down into a number of discrete work packages, where each work package will define a specific amount of work to be done at a particular stage of production. Work packages will initially be generated from the process analysis carried out by production engineers at the tactical level. The object is to produce a coordinated and integrated technical information package for each work package, containing only the information required at that particular stage in the production process. Work packages will be prepared for every stage in production right through to ship completion. (Ref 4)

The following information should be included as a minimum on or with each work instruction:

- flow process of material;
- dimensional data;
- drawings of the interim product;
- work station arrangement;
- production methods;
- material collection.

2.5 Standards

The aim in preparing standards is to reduce variety and ensure suitability for purpose. The benefits that are looked for will differ in emphasis according to the nature of what is being standardized.

The first aim, reduction of variety, is pursued primarily for economic reasons, to reduce the costs of design, manufacture and maintenance. The benefits resulting from series production can become very substantial as the scale of production increases and special-purpose jigs and tools or flow line production are used. The second aim, fitness for purpose, includes factors such as functional suitability, safety, cost effectiveness, reliability, maintainability and quality assurance.

Material standards prescribe the size and scantlings of elementary materials, such as steel plates, sections, pipes, etc, and also include scantlings and configuration of individual fitting pipe pieces, vents, moorings, doors, ladders, etc, which form the basis of design standards. These prescribe the design philosophy criteria, specifications and applications of various structures and systems, and include some basic modules.

Production engineering standards prescribe the methods and criteria of quality control and procedures of testing and inspection. Standard drawings consist of standard equipment layouts of system modules, practices and manuals, etc, which can be utilized as guidance plans.

3: SOME UK EXPERIENCE

3.1 Existing Applications

The concept of design for production is not new, but to some extent it is a concept which has to be continually "rediscovered". Its most recent application dates from around 1980 via programs within British Shipbuilders and in those shipyards which have recently returned to private ownership.

Vaughan (Ref 5) summarises the approach which was adopted as part of an overall productivity improvement program, and which has been developed since. The most significant points made from a design for production perspective are:

- the need for a shipbuilding strategy;
- the development of a contract Build Strategy in parallel with early design;
- subsequent production engineering of the design, ideally within the engineering department.

In the early stages of the program, effort was concentrated on areas of the vessel which have a significant impact

on the total work content and on the ship construction program. Thus a considerable effort was expended on the machinery spaces of vessels and deckhouses.

Initially rapid progress was made with small vessels, notably tugs and supply ships. This reflects the short time between contract and delivery (often little more than one year), which allowed feedback from one vessel to be available quickly. There has been a progression from identifying potential modules (outfit units) on existing designs, to re-routing pipes and systems, to defining modules as part of the initial design. This is now routine for several smaller yards.

Progress has been faster where the design has been more or less within the control of the shipyard. Where an external design is used it has been more difficult to obtain change. At the start of a program of change there is additional design work, in re-working drawings to create more producible layouts and in creating production-oriented work instructions. This additional work is only temporary, provided a thorough review of the drawings supplied for production, classification and owners is made and superfluous drawings are removed. This has been successfully achieved by some smaller shipyards. Where this extra cost is within a single company budget, the trade-offs can be made. Where the extra cost is to be incurred by one company to the benefit of another, there is scope for negotiation.

There are also problems in the development of design for production where vessels are particularly complex or novel. In such cases there is more pressure on design, and less lead time available in which producibility can be considered. There is reluctance on the part of the designer to take on additional changes.

In some cases, the shipbuilder may decide to create lead time by delaying the production start, and use the time to revise the detail design in a more producible form. The additional unbudgeted engineering cost is traded off against production manhour savings. Ref 6 describes such a case in the US. Ref 7 describes current experience at Harland and Wolff, in the case of the SWOPS (Single- Well Offshore Production System) vessel. This is designed to extract oil from isolated, marginal offshore oilfields. The vessel includes dynamic positioning, oil production process plant, storage capacity and accommodation. There was exceptionally close cooperation between design and production requirements.

The reported results of this closer integration included the design and production of large sections of the process plant as complete and independent outfit units. Another development was the integration of major cable runs, in an electrically complex ship, with parts of the structure. This allowed a considerable volume of work to be carried out early in the production cycle. In addition, the build strategy called for numerous outfit units, which were designed in from the earliest stage.

3.2 Some Current Developments

There are a number of current development projects in the Design for Production area. These are in the form of cooperative ventures between shipbuilding companies and universities.

Recent research at the University of Newcastle has been concerned with the development of a preliminary ship design system. The system has a modular structure which allows each module either to be used separately, or used in a fully integrated design system. The main procedures cover: hull form design, compartmentation and layout, structural design and mass estimation, seakeeping and cost estimation (Ref 8).

The work has links with production technology in the influence of build strategy on structural configurations. It is essential that such considerations are accounted for when assessing structural layout and its associated mass. Design for production will be influential in future studies of this type and it will be a significant step forward to be able to assess the effect of major production considerations on the ship design at the concept stage. (Figures 5 and 6)

It is important during the development of a design that alternative proposals can be generated and assessed rapidly. This is particularly true at the concept or preliminary design stage where a large number of alternatives may be examined. In today's competitive environment it is essential that design procedures should be reliable and flexible. The results may be used in pre-contract negotiation and both technical and commercial decisions may be taken on the basis of the data generated. Recent improvements in computing hardware have been accompanied by reduced costs which have made available to the designer a wide range of CAD workstations often incorporating a graphics facility. The advent of this computing power, often in portable "desk-top" form provides an

opportunity for the designer to develop design procedures which are highly inter-active, user friendly and can incorporate more rigorous fundamental analysis methods than are traditionally used in preliminary design. These factors allow the adoption at the concept design stage of methods which have features similar to those normally associated with more detailed or post-contract design investigations.

One important requirement is ship production data in a form comprehensive and reliable enough to be of use in design investigations. Such data includes details of work content and estimates of materials and labour costs associated with each stage of the building programme. It can be combined with a knowledge of build strategy, purchasing policy and production technology to form the basis of a 'design for production' approach when seeking to improve the overall design methodology of marine vehicles. This process has been encouraged by the introduction of sophisticated management and production support systems which are often part of a Computer Integrated Manufacturing System (CIM).

Work has also been carried out to develop a structural design method which incorporates:

- Definition of geometry and scantlings using a graphics facility linked to a database of production information.

- Use of information on production technology and build methods to determine block and panel arrangement.

- Assessment of work content for each phase of production.

- Application of facility cost information to determine total cost for each alternative design.

- Comparison of alternative design proposals on a cost basis.

There is also work on the application of detailed production cost data to structural design, in this case at the University of Glasgow. Further work is currently underway to extend the approach and apply it to warship structures. (Ref 9)

Development is also being undertaken in layout design (Ref 10).

The paper describes work which is being carried out as part of a collaborative research programme between the British

warshipbuilding company, Yarrow Shipbuilders Ltd, and the Department of Naval Architecture at The University of Newcastle upon Tyne, England.

Recent developments in CAD have made available to the designer a wide range of hardware and software which encourage the application of interactive, graphics-based design procedures. Such methods can be of significant benefit in modern warships design where the optimal utilization of "space" is a primary design goal. Two facets which influence and control space management systems are the adjacency of functional areas and the environment into which a space is to be placed. Recent work concerned with the geometric representation and manipulation of architectural arrangements has been adapted for use marine vehicle design. An optimal design procedure which utilizes the theory of fuzzy sets is used to achieve the general layout of space which allows the delineation of the main compartments of a vessel. The hull envelope can be generated using a surface generation module or by using previously faired basis ship offsets held in a data base.

Having defined the compartmental configuration of the functional spaces the next level of design is concerned with a more detailed consideration of compartments, or groups of compartments and the equipment and systems they contain.

Equipment is defined in terms of ergonomic envelopes, geometry and connectivity of services, etc. The attributes of a 3-D graphics workstation are used, in conjunction with an equipment library, to provide an effective detailed design procedure. The layout of equipment in spaces usually concerns the achievement of goals which conflict or have different priorities. The use of optimal goal programming techniques is suggested as a way of solving the multi-objective problem.

3.3 Conclusion

This paper has attempted to re-state the main objectives and requirements for design for production, to describe the application of production engineering to design and to relate this to current shipbuilding practice.

Initially, the application has been in the form of modifications to existing designs, at the detail level. More recently the integration of producibility into the design process has started earlier. The main factors in

Allowing this earlier integration are the existence of reliable production data from a relatively stable production system, and the emergence of sophisticated computer software for initial design. This allows greater depth of analysis in a shorter timescale. The designer has therefore the opportunity to review additional options, and to take into account the impact of design variations on production. The use of these newer methods is being consolidated into a formal design system.

It is to be hoped that the potential being offered to reduce shipbuilding costs will be realized.

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The opinions expressed are the author's own.

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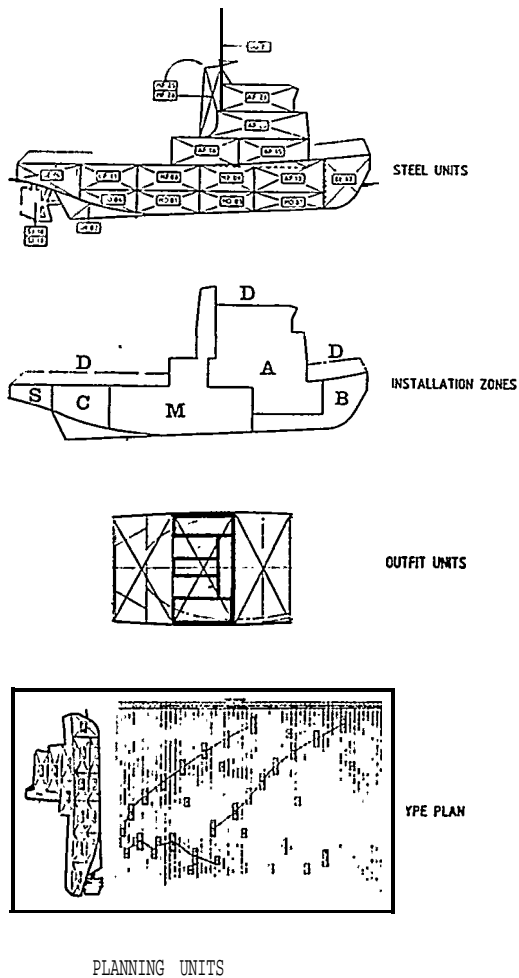


FIGURE 1 - Identification of Planning Units

These are identified at the earliest stage of the design process, and serve as the basis of all planning activities, detailed design and engineering.

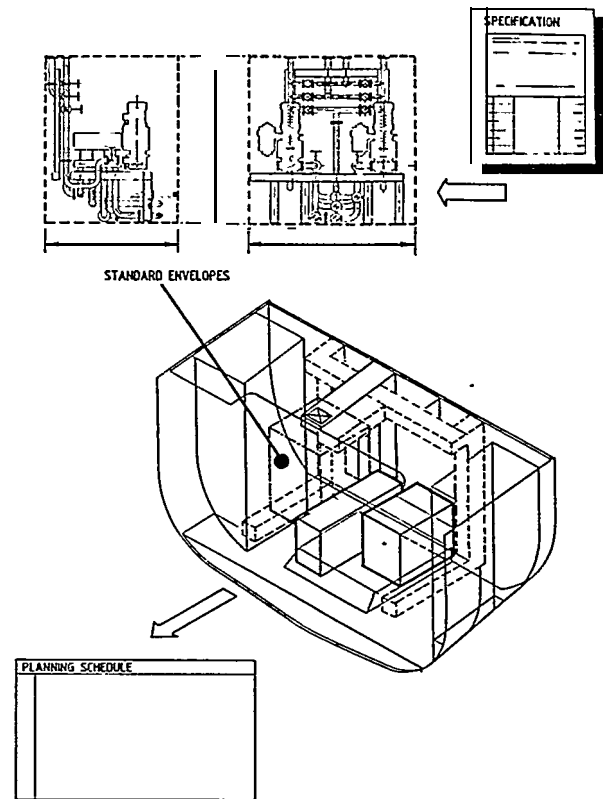
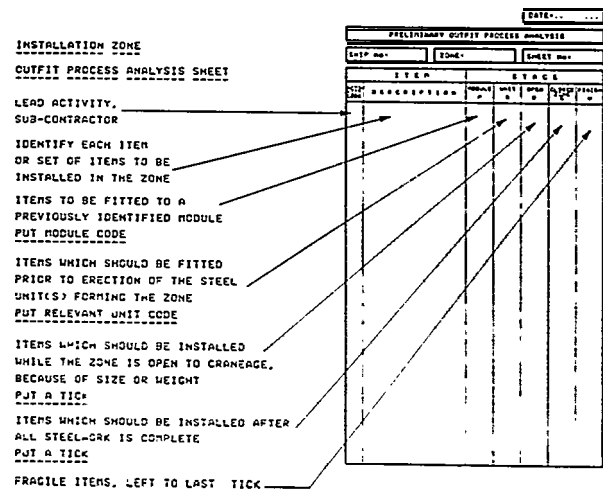


FIGURE 2 - Spatial Analysis

The ship is designed as a set of related functional spaces, based on standards where possible, which provide envelopes for equipment, system, access and maintenance requirements.

FIGURE 3 - Process Analysis

Each planning unit is analyzed, in the case of outfit to establish at which stage of production items will be installed. A further analysis of each stage will determine work package content.



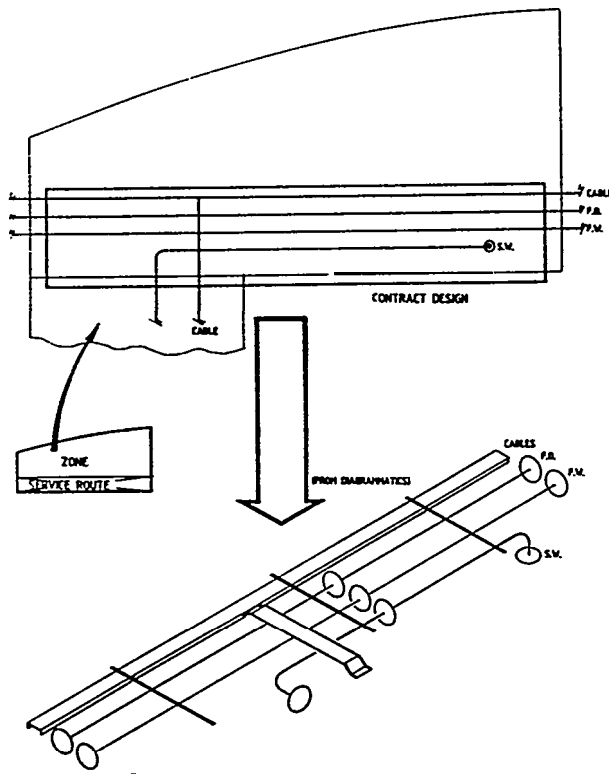


FIGURE 4 - Identification of Outfit Assemblies

The service route, identified as a functional space and part of a planning unit, provides the basis for outfit assemblies and defines detail design requirements.

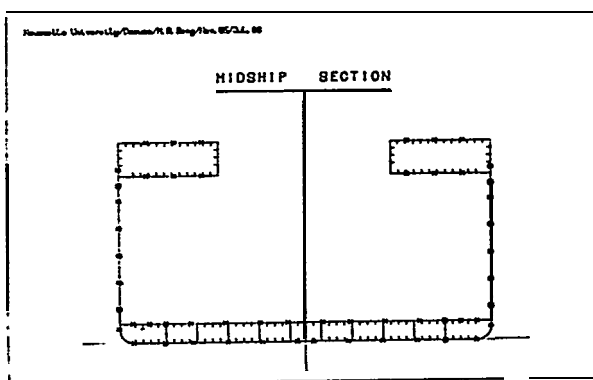


Fig. 6.12 Midship Section (BLOCK/UNIT DIVISION: 7 UNITS)

FIGURE 5 - Concept Design

Recent developments in computer software have provided powerful tools to allow design options to be created and evaluated early in the design process.

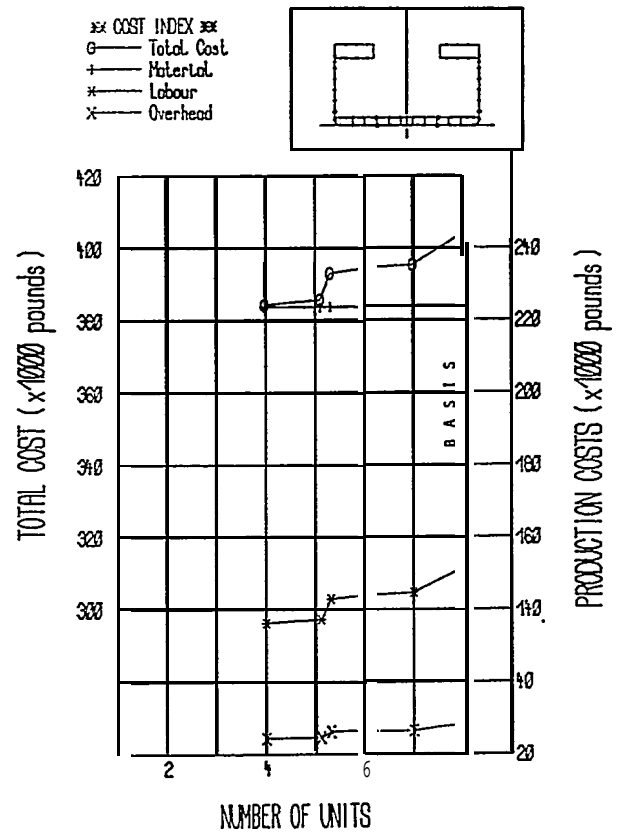


FIGURE 6 - Cost Evaluation

The depth of information which can be produced at an early design stage, linked to a production performance database, allows the production cost of various options to be evaluated.

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